International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

Performance Analysis of a DC Series Motor Coupled with a DC Shunt Generator Using a Control Panel

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Abstract - **In electrical engineering, if the excitation or speed of a D.C. shunt generator is not properly controlled, it may fail to develop the desired voltage, or even damage connected equipment during testing. Similarly, improper loading conditions may cause overheating or instability in machine performance. In the case of a D.C. series motor, absence of a proper control circuit may result in incorrect rotation, which can affect the working of systems.**

This problem can be solved by using a specially designed control panel that allows safe and accurate measurement of voltage in a DC shunt generator by varying flux and speed, conducting a load test to study its performance under different conditions, and ensuring the reversal of rotation of a DC series motor through a controlled switching arrangement. The panel provides protective features, clear monitoring points, and flexibility for experimental verification.

Keywords - DC Machines, DC Series Motor, DC Shunt Generator, Open Circuit Characteristic, Load Characteristics, Direction Control, no-load tests and load test

Literature Survey

DC machines are still commonly employed in academic laboratories and industry because of their easy construction, limited control and well-defined characteristics. A number of researchers have examined the operation and nature of DC shunt generators and DC series motors in various conditions of operation.

In their article published in the IEEE Transactions on Energy Conversion, K. R. Raja Gopal and S. K. Pillai provided an in-depth description of the characteristics of DC shunt generator with adjustable excitation. The proposed research is concerned with the impact of field excitation on the terminal voltage, armature current and the general voltage control of the DC shunt generator. The findings indicate that excitation variation has a substantial contribution to open-circuit and load characteristics, and excitation control makes a significant parameter in the analysis of performance of DC shunt generators.

Y. Anagreh explored the constant operating operation of a DC series motor that was driven by a self-excitatory wind-driven induction generator. The article, which appeared in Rev. Energ. Ren.: Power Engineering, studies the characteristics of interaction between the output of the generator and the load of the motor. The work contains valuable informative material on the behavior of generators loads and its impact on the performance of DC motors in different load conditions despite the fact that the main emphasis is placed on renewable energy integration.

DC machines are fully explained theoretically and experimentally in standard textbooks like A Textbook of Electrical Technology by B. L. Theraja and A. K. Theraja. The book discusses the construction of DC shunt generators and DC series motors and their working

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principles and characteristics. It also explains the typical experimental practices such as no-load (open-circuit) test, load (closed-circuit) test, and reversal of the direction of the motor rotation. These tests play a critical role in the laboratory test setups to understand the voltage regulation, efficiency, speed petrol characteristics and the direction control of DC machines.

Based on the literature reviewed, it is clear that the combination of experimental analysis and theoretical modeling is central in the knowledge of the working of DC shunt generators and DC series motors. Few studies have however been documented as of integrated control panels that examine motorgenerators combinations under different load conditions. This informs the current work, which dwells on the experimental research and performance assessment of a DC series motor, in combination with a DC shunt generator, based on commonly used test procedures.

I. INTRODUCTION

Control Panel of a DC Series Motor and DC Shunt Generator is a complete experimental apparatus which aims at demonstrating and analysing the basic principles of DC machines and their skills in practical implementation of electrical engineering. In this system, a DC series motor is used as the prime mover device that transforms electrical energy into mechanical energy to cause the DC shunt generator to move as a result of a common shaft. This, in its turn, makes the generator change this mechanical energy into electrical energy and, therefore, creates an effective system of energy conversion electromechanical. These parts are all that guarantee safe, flexible and efficient functioning of the arrangement. The panel setting enables students and engineers to carry out various tests and monitor the nature of performance of the generator in varying conditions.

The main aim of the experiment is to perform open-circuit (no-load tests) and close circuit (load tests) of DC shunt generator. In the open-circuit test the generator is not loaded and the voltage generated, at constant field current and speed, is measured and the result is the Open Circuit Characteristic (O.C.C.), indicating the dependence of the field excitation on the resulting e.m.f. The load test method involves a gradual loading of the load rheostat to the generator and subsequent values of terminal voltage and current are taken to plot the Load Characteristic Curve, which is the variation of terminal voltage with load current. These attributes assist in the study of the internal behavior of the generator, such as, armature reaction and internal voltages drops.

Also, the arrangement can be used to show the reversal of motor rotation, possible by either reversing the armature or the field connections of the DC series motor (although not both at the same time). This is the characteristic of the simplicity of direction control in DC machines.

On the whole, the Control Panel of the DC Series Motor accompanied with DC Shunt Generator is a well-organized and secure experimental design that fills the gap between theory and practice. It does not only add more knowledge on how the DC machine works, but also builds the analytical and technical skills needed to operate electrical machines in the real world scenario. The setup is a useful educational aid in the study of the properties of DC motor-generators, control procedures, and performance measures in the laboratory and industry.

II. CIRCUIT DIAGRAM AND EXPLANATION-

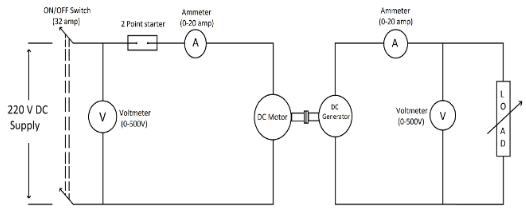

Fig 1: Circuit diagram

This circuit is a mechanical coupling of a DC series motor and a DC shunt generator. A DC supply is then fed via a DPST switch which functions as the primary isolating switch to allow connection and disconnection of the supply safely. The application of a voltmeter compares the supply to the motor voltage. To measure the starting and running current of the DC series motor the supply then is connected to a two-point starter, which in turn is connected in series with an ammeter. The series rheostat is connected in series with the motor also to regulate the current and consequently the speed of the motor when in operation (in some test the rheostat is not connected). The motor in the DC series changes the electric energy into mechanical energy and its shaft is mechanically linked with a DC shunt generator.

The DC shunt generator is then mechanically connected to a DC motor and transforms the mechanical energy into electrical energy. Ammeter is placed in series with external load at the terminals of the generator and voltmeter is placed across the terminals of the generator to measure the load current and output voltage, respectively. A variable load is across the generator to adjust the load current and investigate the performance of the generator at various loadings. Therefore the motor circuit, and generator circuit are electrically independent and

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mechanically coupled using a shaft, which permits controlled testing of the two machines.

Components-

DC shunt generator:
In a shunt generator the winding of the armature is connected in parallel with the field winding in such a way that the terminal voltage of a generator is across the winding. The winding of the shunt field contains a large number of turns of fine wire with high resistance. Thus, armature currents only pass through shunt field winding, and the rest pass through the load. Figure displays the relationships of a shunt generator. The current Ia through the armature is divided into two components a small portion, Ish, passes through shunt field winding as the major portion IL passes on to the externa load.

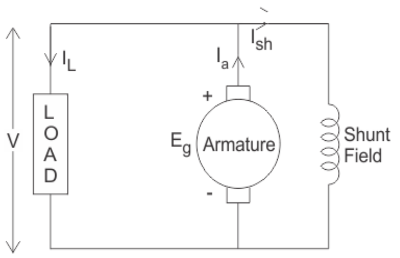

Fig 2: circuit of DC shunt generator

Internal characteristic:
The internal characteristic curve is the curve between the generated voltage Eg and the load current IL. Armature reaction reduces the voltage generated when loading the generator. The generated voltage will, then, be less than the emf generated at no load. In this case, the internal characteristic curve is AB and AD curve is no load voltage curve as shown in the figure below.

External or Load characteristic:
AC curve is exhibiting the exterior trait of the DC shunt generators. It is indicating the change of terminal voltage by load current. Armature resistance causes ohmic drop, which provides lesser terminal voltage with the generated voltage. The reason why the curve is lower than the inner characteristic curve is because of this.

$$V = (E_g - I_a R_a) = E_g - (I_L + I_{sh}) R_a$$

The terminal voltage is always determined at constant by varying the load terminal. External properties of shunt dc generator under conditions of reduced load resistance of a DC shunt generator, the load currents of the generator rose as illustrated in above figure. However, the load current may be increased to some tolerance with (to point C) the reduction in the load resistance. Beyond this, it demonstrates a reversal of the characteristic. Any reduction in load resistance causes a reduction in current hence external characteristic curve reverses back as indicated in the dotted line and finally the terminal voltage is zero. There is some residual magnetism voltage. We know, that terminal voltage According to increase of IL, terminal voltage diminished. Beyond some threshold point, terminal voltage is decreased drastically due to high load current and higher ohmic drop. This extreme change of terminal voltage across the load causes the decrease in the load current at the time of load at high value or at low load resistance. That is why the resistance of the machine load should be taken good care of. Maximum current output by the machine is referred to as breakdown point (point C in the figure).

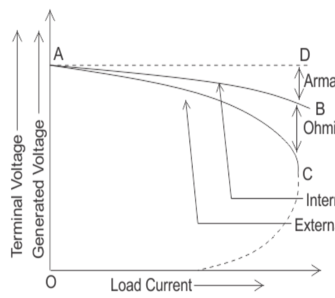

Fig 3: Load characteristics of DC shunt generator

DC series motor:
A series motor DC motor is a type of DC motor where a field winding is in series with the armature such that the current passes through both.
In DC supply, the current is carried through the series field winding and the armature respectively. The current results in a very powerful magnetic field in the field winding. Meanwhile, armature conductors conduct current, and they are put in this magnetic field. Fleming left-hand rule states that the armature conductors are acted upon by a force, which causes the armature to turn and, therefore, produce mechanical movement.

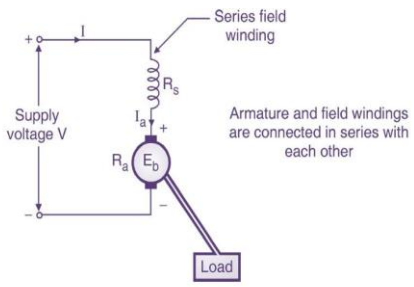

Fig 4: Circuit diagram
Torque Armature Current Characteristic:

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At low currents in a DC series motor the square of armature current is directly proportional to the torque since both the flux and armature current are rising in the same direction. In this way the motor produce extremely high starting torque.

Speed Armature Current Characteristic:
The slower the DC series motor run the more armature current is needed. When the load is small, the flux and the armature current are small and thus, the motor moves at a very high speed and when the load is large, the speed decreases because of the increased current.

Torque Speed Characteristic:
A DC series motor has a very non-linear torque speed characteristic. This motor gives high torque at low speed and with high speed, the torque drops at an alarming rate. Such feature results in the motor not being able to run with no load, as it is too fast.

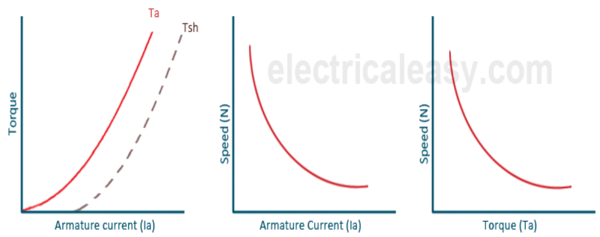

Fig 5: Characteristics of DC series motor

Motor and Generator Rating Chart:

Parameter	Motor	Generator
Power	3.0 HP	2.2 HP
Supply Voltage	220V	220 V
Armature Voltage	—	220 V
Armature Current	12.1 A	11.1 A
Field Voltage	—	220 V
Field Current	—	0.9 A
Speed (RPM)	1500	1500

III. WORKING-

When the supply is turned on the DC series motor takes electricity and starts rotating. Since the motor and generator are mechanically coupled together on a mutual shaft, the generator also begins to rotate at the same rate. The current rotation of the generator armature in the magnetic field causes an electromotive force (e.m.f.) according to the Law of Electromagnetic Induction described by Faraday.
The strength of the e.m.f. induced is primarily determined by the field flux (Φ) which is created by the field winding of the generator, and The speed of rotation (N) of the generator shaft.
The generated e.m.f. is given by the expression**:**

$$E_g = P\Phi ZN / 60A$$

Where :
P = number of poles
Φ = flux per pole (in Weber)
Z = total number of armature conductors
N = speed in r.p.m.
A = number of parallel paths in the armature

- No-Load (Open Circuit Test)-

In this test the generator is left unloaded, and field winding excited directly without the provision of a field rheostat (it is not in the circuit). The field current is therefore kept constant throughout the observation. Since the motor makes the generator run at a constant speed, the voltage that is produced as e.m.f. is measured with a voltmeter across the generator terminals.
The Open Circuit Characteristic (O.C.C.) of the DC shunt generator may be charted by plotting the voltage induced at a certain constant excitation at a constant speed. This property aids in the analysis of the correlation of the field excitation and the voltage that is produced.

- Load Test(Close Circuit test)-

Once the open-circuit characteristics have been investigated, loading of the generator is done by setting the load bank across the terminals of the generator. The armature reaction and internal armature and brushes voltage drop decrease slowly with the increasing load current, as the terminal voltage decreases.
At the various load conditions, the appropriate voltmeter and ammeter values are noted. One then plots the Load Characteristic Curve whose curves reveal how terminal voltage changes with load current in the DC shunt generator.

- Reversal of Motor Rotation-

The reversal of rotation of the DC series motor can also be demonstrated by the same installation. This is done by inverting either the armature connections or the field connections but not both at the same time. This principle is applied in practice in different applications where there is a necessity of the direction in which the change of movement should take place.
Significance of the Setup:
This experimental design helps to understand clearly the working behavior of a DC series generator when it is in a no-load and loaded condition. It is also useful in

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investigating the influence of excitation (flux) and shaft speed to the voltage generated.
Use of necessary tools like ammeters, voltmeters, switches. This type of control panel is not only useful in educational laboratories to train students but also the demonstration unit is useful in the industry.

IV. OBSERVATION TABLE :

- **Calculations:**

Conversion of HP to Watts:

1 HP = 746 W

Motor Power:

Pm = 3 × 746

Pm = 2238 W

Generator Power:

Pg = 2.2 × 746

Pg = 1641 W

- **Electrical Input Power to Motor**

Formula:

P = V × I

- **At Full Load (Observation 3):**

Pin = 235 × 11.02

Pin = 2590 W

- **Electrical Output Power of Generator:**

Pout = Vg × IL

At Full Load:

Pout = 179 × 7.08

Pout = 1267.32 W

- **Overall System Losses**

Losses = Pin − Pout

Losses = 2590 − 1267.32

Losses = 1322.68 W

- **Losses include:**

Copper losses (motor + generator)

Mechanical losses

Core losses

- **Overall Efficiency of Motor–Generator Set**

Formula:

η = Pout / Pin × 100

η = 1267.32 / 2590 × 100

η = 48.93 %

Sr. No.	Motor Input voltage	Motor Armature current (Ia=Is)	Speed (rpm)	Torque (N·m)	Generator Output voltage	Load current
1	238 V	8.16 A	1790	10.36	288 V	2.53 A
2	236 V	10.00 A	1594	14.13	228 V	5.19 A
3	235 V	11.02 A	1388	17.83	179 V	7.08 A

- **Generator Voltage Regulation**

Formula:

%VR = (VNL − VFL) / VFL × 100

No-load voltage VNL = 288 V

Full-load voltage VFL = 179 V

%VR = (288 − 179) / 179 × 100

%VR = 60.89 %

- **Speed Regulation of Motor**

Formula:

%SR = (NNL − NFL) / NFL × 100

No-load speed NNL = 1790 rpm

Full-load speed NFL = 1388 rpm

%SR = (1790 − 1388) / 1388 × 100

%SR = 28.96 %

- **Torque Relation (Theory Confirmation)**

For DC Series Motor:

$T \propto Ia^2$

As armature current increases from 8.16 A → 11.02 A, torque increases, enabling the motor to drive higher generator load.

- **Torque Calculation:**
- **Reading 1 (No Load)**

Given:

V = 238 V

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I = 8.16 A

N = 1790 rpm

Step 1: Power

P = 238 × 8.16

P = 1942.08 W

Step 2: Angular speed

ω = 2π × 1790 / 60

ω = 187.45 rad/s

Step 3: Torque

T = 1942.08 / 187.45

T = 10.36 N·m

- **Reading 2**

Given:

V = 236 V

I = 10 A

N = 1594 rpm

Step 1: Power

P = 236 × 10

P = 2360 W

Step 2: Angular speed

ω = 2π × 1594 / 60

ω = 166.86 rad/s

Step 3: Torque

T = 2360 / 166.86

T = 14.13 N·m

- **Reading 3 (Full Load)**

Given:

V = 235 V

I = 11.02 A

N = 1388 rpm

Step 1: Power

P = 235 × 11.02

P = 2590 W

Step 2: Angular speed

ω = 2π × 1388 / 60

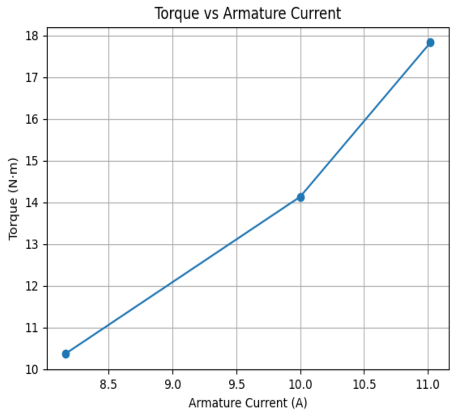
ω = 145.35 rad/s

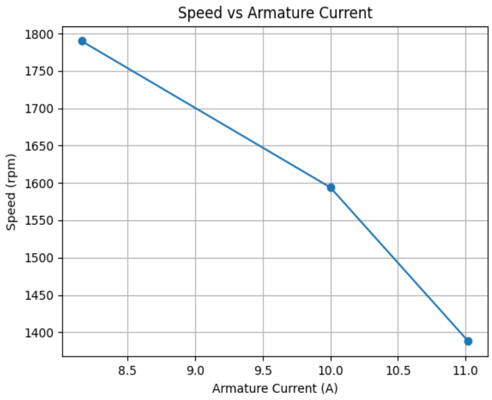
Step 3: Torque

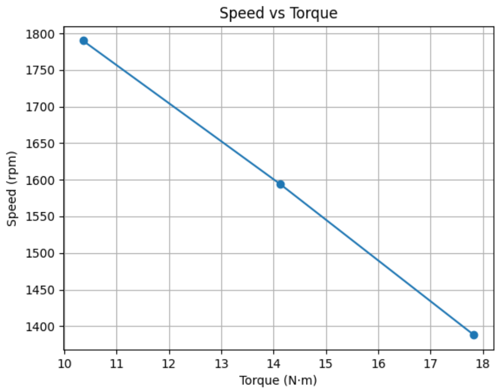
T = 2590 / 145.35

T = 17.83 N·m

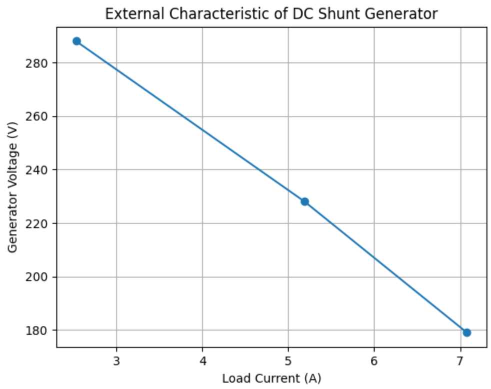
- **Characteristics of DC series motor**







- **Load characteristics of DC shunt generator**



V. CONCLUSION-

This paper is an analysis of the working of a DC series motor and a DC shunt generator. The conversion of electromechanical energy is confirmed in real life experimentation. Open-circuit and load behaviour of the DC shunt generator is obtained and analysed to assess its behaviour in different operating conditions. The research also gives practical works with the elements of control panels and measurement tools, as well as the idea of safe working conditions and directional control of DC motors. On the whole, the experiment assists in developing practical and analytical skills associated with the evaluation of the functionality of DC machine and proves that the configuration is a useful learning resource both in educational and practical learning of DC machines.

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